An Ontology-Based Semantics for the Motivation Extension to ArchiMate

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Abstract— The "motivation domain" of an Enterprise Architecture addresses objectives in a broad scope ranging from high-level statements expressing the goals of an enterprise to declarations of requirements on business processes, services and systems. An important development regarding the incorporation of the motivation domain in a comprehensive Enterprise Architecture modeling language is the upcoming Motivational Extension to ArchiMate (based on the ARMOR language). The extension proposes the inclusion of concepts such as concerns, assessments, goals, principles and requirements to ArchiMate. We believe that careful definition of the semantics of these concepts is required, especially when considering that the motivation domain addresses subjective aspects of the enterprise. To address that, this paper focuses on an ontology-based semantics for the Motivation Extension. We interpret the concepts by using the Unified Foundational Ontology (UFO) as a semantic domain, and, as a result, propose well-founded recommendations for improvements of the extension.

Keywords: Enterprise Architecture Modelling, Ontology-based Semantics, Goal Modelling, ArchiMate, UFO

I. INTRODUCTION

The motivation domain is concerned with "why" an Enterprise Architecture is defined the way it is. This domain addresses objectives in a broad scope ranging from high-level statements expressing the goals of an enterprise to declarations of requirements on business processes, services and systems.

Although the importance of the motivation domain for Enterprise Architecture has been recognized two decades ago with the inclusion of the "motivation"/"why" column in the Zachman framework [1], Zachman did not define basic concepts for this column, justifying that "there is a scarcity of good examples in the […] motivation column" and stating that "the why column would be comprised of the descriptive representations that depict the motivation of the enterprise, and the basic columnar model would likely be ends-means-ends, where ends are objectives (or goals) and means are strategies (or methods)" [1]. So far, the modeling of motivation has been an active area of research in software and requirements engineering [2], [3], with few comprehensive enterprise modeling approaches addressing the why column [4].

An important development regarding the incorporation of the motivation domain in a comprehensive Enterprise Architecture modeling language is the upcoming Motivational Extension to ArchiMate (based on the ARMOR language) [5]. To address the motivational aspect of the enterprise, a goal-oriented requirements modeling language named ARMOR was developed [5]. The design of the language was driven by extensive analysis of existing works and is considered to have a "more sophisticated support" for goal related concepts when contrasted with a number of enterprise modeling techniques [6]. The ARMOR language has evolved into the proposed Motivation Extension for the ArchiMate framework [7].

The extension proposes the inclusion of concepts such as concerns, assessments, goals, principles and requirements to ArchiMate, among others. The aim of the extension is to represent the strategies that shape an Enterprise Architecture. It defines relations between the various concepts to capture how changes in enterprise's goals can have significant consequences throughout the enterprise in an attempt to accomplish the changing objectives.

Similarly to other goal modeling approaches, the initial development of the Motivation Extension has been conducted without a formal definition of its concepts. We believe that careful definition of the semantics of these concepts is required, especially when considering that the motivation domain addresses subjective aspects of the enterprise. The absence of such careful definition could lead to several modeling and communication problems. For example, different modelers may ascribe different meanings to the same modeling elements. When sharing a model, this could lead to the False Agreement Problem [8], in which each modeler would come to a different interpretation of the same model and would not detect the conflict. This is particularly challenging given that an Enterprise Architecture model is a joint effort involving several stakeholders and requiring the integration of several architectural domains into a coherent whole. The lack of common interpretation for the various modeling elements would lead to integration problems in the organization and information misuse, regardless of whether the models adhere syntactically to the same metamodel.

This paper aims at addressing these problems by explicitly defining the semantics of ArchiMate's proposed Motivation Extension. To accomplish this we analyze and

interpret the concepts of the Motivation Extension in terms of a foundational ontology, i.e., a formal and ontologically sound system of domain-independent categories. In particular, we make use of the Unified Foundational Ontology (UFO) as our semantic foundation.

UFO has been chosen because it unifies several foundational ontologies and has been successfully employed to evaluate, re-design and integrate the models of conceptual modeling languages as well as to provide real-world semantics for their modeling constructs. Further, UFO addresses social and intentional phenomena, which are modeled by the motivation domain. This foundational ontology has been previously used successfully to semantically analyze the Architecture of Integrated Information Systems (ARIS) framework for enterprise modeling [9], to semantically integrate the ARIS framework to the goal modeling language Tropos [4], to investigate the semantics of role-related concepts in ArchiMate and a number of Enterprise Modeling approaches [10], and to provide the analysis and re-design of agent-oriented goal modeling languages [11].

While our effort in this paper is concerned with the semantics of the motivational extension, we believe this is a first step towards the semantic integration of the motivation domain with other architectural domains.

This paper is further structured as follows. Section II briefly describes the proposed Motivation Extension to ArchiMate; Section III introduces the concepts used in our analysis and section IV provides an interpretation for each metamodel element, proposing recommendations to the Motivation Extension as a result of ontological analysis. Section V discusses related work and, finally, section VI presents our conclusions and discusses future work.

II. AN OVERVIEW OF ARCHIMATE'S PROPOSED MOTIVATION EXTENSION

The ArchiMate 1.0 Specification [12] described one of its future directions as "extending and refining the concepts" of "strategy, goals, principles and requirements". The Motivation Extension (ME) has been proposed to fulfill this gap by including a motivation column in the ArchiMate framework (see Figure 1) and proposing additional modeling concepts to address the management of goals and requirements [7].

Fig. 1. Motivation Extension in the ArchiMate Framework [7]

The ME is an evolution of ARMOR [5]. The design of ARMOR was driven by a rigorous analysis of existing works

in the goal and requirements modeling area. For this reason, many concepts of other languages, such as i*/Tropos [2] and Kaos [3], have influenced the development of the language.

Figure 2 shows an example of an ME model (adapted from the ME whitepaper [7]). It depicts part of the stakeholders' view of an organization that sells insurances. This view shows two *stakeholders*: the 'Board' and the 'Customer'. Each *stakeholder* has a number of *concerns*, which may be shared as shown by the 'Customer satisfaction' *concern*. Analysis of this *concern* leads to the *assessment* 'Complaining customers'. The 'Board' *stakeholder* also has a 'Costs' *concern* and its analysis leads to the *assessment* 'Employee costs too high'. The goal 'Reduce workload employees' addresses this *assessment*. This *goal* is decomposed into the *sub-goals* 'Reduce manual work' and 'Reduce interaction with customer'. The *principle* "Systems should be customer facing" realizes both *sub-goals* and is specialized into the *requirements* "Provide on-line portfolio service" and "Provide on-line information service".
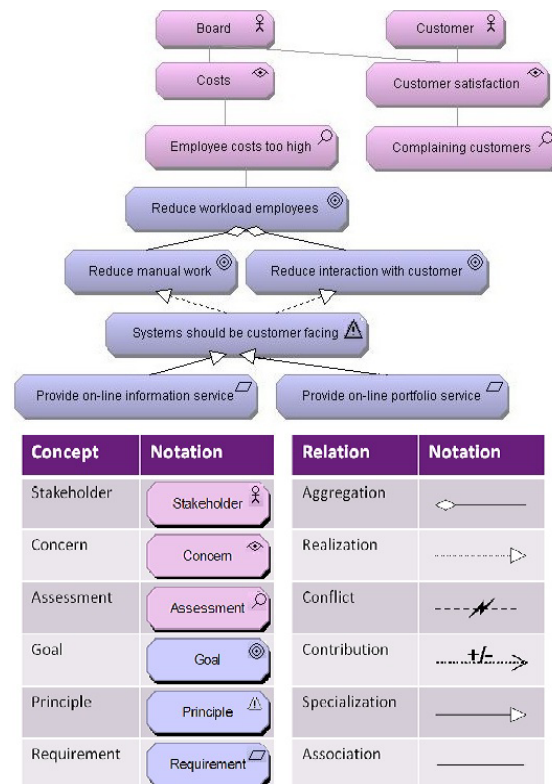

Fig. 2. ME Example adapted from the ME whitepaper [7]

Figure 3 shows the ME metamodel revealing the concepts of *stakeholder*, *concern* and *assessment* (specializations of the 'problem element' metaclass) as well as *goal*, *principle* and *requirement* (specializations of the 'intention' metaclass).

 Goal is one of the key concepts, and "a goal represents some end that a stakeholder wants to achieve." "Some end" is anything a stakeholder may desire, such as a state of affairs, a produced value or a realized effect. A *Requirement* represents "a desired property that must be realized by a

system." The term 'system' is used with a large scope and may refer to any element of the enterprise architecture, including structural, behavioral or informational elements, such as data objects, information systems, business actors or business processes. The *Principle* concept "represents a general desired property that guides the design and evolution of systems in a given context." *Principle*s are broader in scope and more abstract than *requirement*s. "A *principle* defines a general property that applies to any system in a certain context." To enforce that some system conforms to a *principle*, it is necessary to specialize the *principle* into *requirements* on the system.
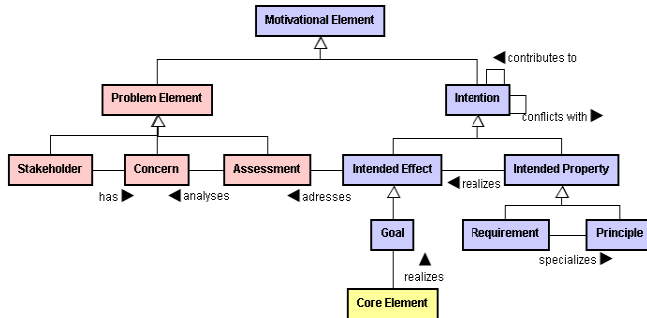

Fig. 3. ME Metamodel [7]

The relationships involved in the specializations of *Intention* are described below. The *contributes to* relationship "models that the realization of some intention contributes positively or negatively to the realization of another intention". The *conflicts with* relationship "models that the realization of two intentions mutually exclude each other. It is used to describe that two intentions cannot be realized both, and as such are in conflict with each other". The *specialization* relationship "indicates that an object is a specialization of another object. In the current context, this relationship is used in particular to describe that a principle is specialized into a requirement". And the *realizes* relationship, which models that "some end is realized by some means. *Realization* is used to describe how: (i) A *goal* (the end) is *realized* by a *principle* or *requirement* (the means); (ii) A *requirement* (the end) is *realized* by a *system* (the means), which can be represented by a passive structure element, a behaviour element or a passive structure element." (These elements are actually present in the ArchiMate metamodel and represented in the ME by the *Core element* abstract metaclass.) We now focus on the concepts that specialize *Problem Element*. The *Stakeholder* concept "represents an individual, team, or organization with an interest in the outcome of the architecture." The *Concern* concept represents "some key interest that is important to certain stakeholders in a system, and determines the acceptability of the system. A *concern* may pertain to any aspect of the system's functioning, development, or operation, including non-functional considerations such as performance and security." The *Assessment* concept represents "the outcome of the analysis of some concern, revealing the strengths, weaknesses, opportunities or threats that may trigger a change to the enterprise architecture." And

"new or adapted business goals" can be defined to *address Assessments*.

The *association* relationship from ArchiMate is reused to relate *stakeholders* to *concerns* and *concerns* to *assessments*. A *stakeholder* may have multiple *concerns*, and a *concern* may be shared by multiple *stakeholders*. An *assessment* typically assesses a single *concern*, but could involve multiple *concerns*. A *concern* may be analyzed through multiple *assessments*. The *analyzes* relationship misses a formal or informal description in the whitepaper. We assume the definition given on the Cambridge Learner's dictionary, as "to examine the details of something carefully, in order to understand or explain it". The *aggregation* relationship "models the decomposition of some intention, i.e., a goal, requirement or principle, into more fine-grained intentions". (The aggregation relation has been omitted from the metamodel in Figure 3, but is applicable to all ArchiMate metaclasses. Thus, any modeling element may be related to another modeling element of the same type through the aggregation relation.)

III. ONTOLOGICAL FOUNDATIONS

In this section we briefly discuss a fragment of the ontological foundations in line with the purpose of this paper. We make use of the Unified Foundational Ontology (UFO) as our semantic foundation. For a full discussion regarding this ontological foundation, refer to [13][14].

A fundamental distinction in this ontology is between the categories of underlined individuals and universals. Universals are predicative terms that can be applied to a multitude of individuals, capturing the general aspects of such individuals. Individuals are entities that exist in reality possessing a unique identity and that can instantiate a multitude of universals.

Further, UFO makes a distinction between the concepts of endurants and events. Endurants are individuals that persist in time while keeping their identity, in the sense that if we say that in circumstance *c1* an endurant *e* has a property *p1* and in circumstance *c2* a property *p2* (possibly incompatible with *p1*), it is the same endurant *e* in each of these situations. Examples can include a particular person (say Peter) weighting 70kg in one circumstance and 78kg in a different circumstance, being the same individual (Peter) in all circumstances. Other examples include organizations (the University of Twente, the Federal University of Espírito Santo) and everyday objects (a ball, an apple, etc.). Events, in contrast, are individuals composed of temporal parts, they happen in time in the sense that they extend in time accumulating temporal parts. Examples include a particular execution of a business process, a meeting or a birthday party. Whenever an event occurs, it is not the case that all of its temporal parts also occur. For instance, if we consider a business process "Buy a Product" at different time instants, at each time instant only some of its temporal parts are occurring.

A substantial is an endurant that does not depend existentially on any other individual, what is usually referred by the common sense term "object". In contrast with substantials, moments (also known as 'abstract particulars' and Tropes

[15], [16]) are existentially dependent entities, i.e, for a moment x to exist, another individual must exist, named its bearer. Examples of moments include a color, a marriage, an electric charge on a conductor, etc. Existential dependence can be used to differentiate intrinsic and relational moments. Intrinsic moments are dependent on a single individual, while relational moments (also called relators) depend on a plurality of individuals. Examples of the first include weight and color, while examples of the latter include marriage and employment.

An agent is a specialization of substantial, representing entities capable of bearing intentional moments. These include mental states such as individual beliefs, desires and intentions. Intentionality should not be understood as the notion of "intending something", but as the capacity to refer to possible situations of reality. This is captured in UFO with the notion that every intentional moment has an associated proposition which is called the propositional content of the moment. In general, the propositional content of an intentional moment can be satisfied (in the logical sense) by situations in reality. Every intentional moment has a type (belief, desire or intention). The propositional content of a belief is that which an agent holds as true. Examples include one's belief that the Eiffel Tower is in Paris and that the Earth orbits around the Sun. A desire expresses the will of an agent towards a state of affairs (e.g., a desire that Brazil wins the Next World Cup), while an intention express desired state of affairs for which the agent commits at pursuing (internal commitment) (e.g., my Intention of going to Paris to see the Eiffel Tower).

Actions are intentional events, i.e., events with the specific purpose of satisfying (the propositional content of) some intention of an agent. The propositional content of an intention is termed a goal. Only agents are said to perform actions [4], as opposed to non-agentive objects which participate (non-intentionally) in events.

Agents can be further specialized into physical agents (e.g., a person) and social agents (e.g., an organization).

Social agents are further specialized into institutional agents and collective social agents. Institutional agents are composed of a number of other agents exemplifying what is termed a functional complex. "The parts of a functional complex have in common that they all posses a functional link with the complex. In other words, they all contribute to the functionality (or the behavior) of the complex" [13]. In addition to institutional agents, UFO also acknowledges the existence of collective social agents which are distinguished from institutional agents in that all its members play the same role in the collective.

Similarly to agents, non-agentive objects can be specialized into physical objects and social objects. A category of social objects of particular interest to us is that of normative description. Normative descriptions are social objects that create social entities recognized in that context. Examples of normative descriptions include a company's regulations and public laws. Examples of social entities that can be defined by normative descriptions include social roles (e.g., president, manager, sales representative), social role mixins (whose instances are played by entities of different kinds, e.g., customer, which can be played by persons and organizations), social agent universals (e.g., that of political party, education institution), social agents (e.g., the Brazilian Labour Party, the University of Twente), social object universals (e.g., currency) and other social objects (e.g., the US dollar) or other normative descriptions (e.g., a piece of legislation). Normative descriptions are recognized by at least one social agent. Figure 4 shows a fragment of the specializations of individuals in UFO.

IV. ONTOLOGICAL INTERPRETATION

In this section we present the Motivation Extension ontological interpretation. Using as a starting point the original ME definitions from [7] as discussed in section 2, we analyze each ME concept and discuss its possible ontological interpretations. We structure this section in four subsections. The first subsection comprises specializations of
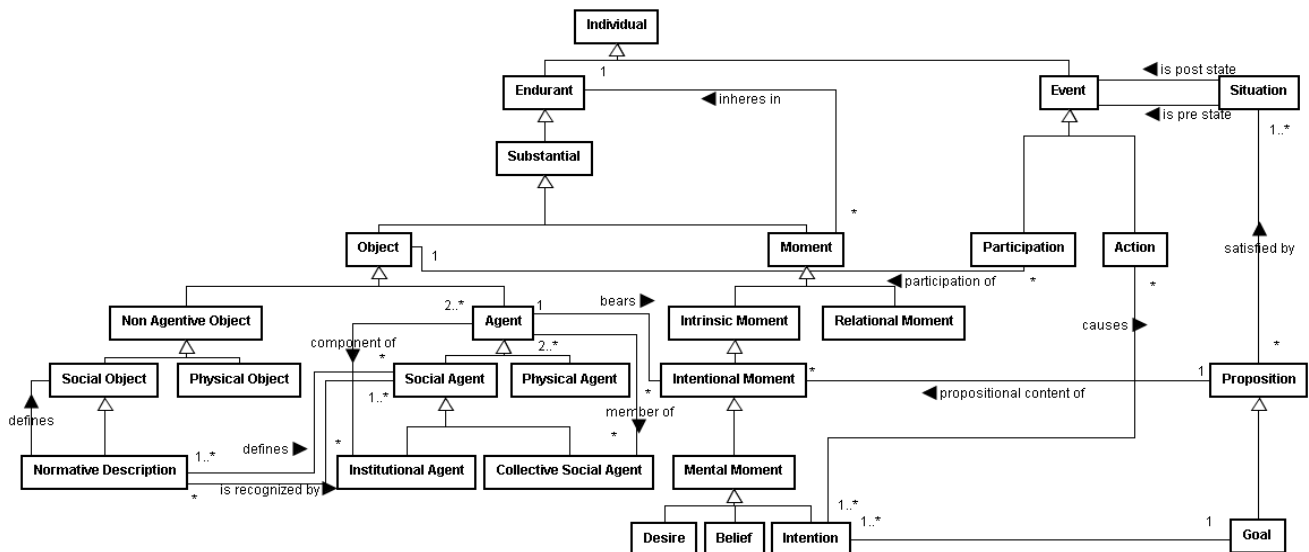

Fig. 4. Fragment of UFO depicting specializations of Individual

the ME's abstract metaclass *Problem Element*. The second subsection comprises specializations of the ME's abstract metaclass *Intention*. The third subsection analyzes the relationships that are common to all concepts. Finally we present an example. A table summarizing the interpretation results is provided as an appendix.

A. Analysis of specializations of Problem Element

We start our analysis with the concepts that specialize *Problem Element*, namely *Stakeholder, Concern* and *Assessment*.

The *Stakeholder* concept in the ME has been borrowed from the TOGAF framework [17]. TOGAF defines stakeholder as "an individual, team, or organization (or classes thereof) with interests in, or concerns relative to, the outcome of the architecture". A *stakeholder* is an entity able to refer to the reality (in this case "the architecture"). Accordingly, it is interpreted as an <u>Agent</u> in UFO, a <u>substantial</u> that bears <u>intentional</u> <u>moments</u> (such as <u>beliefs</u>, <u>desires</u> and <u>intentions</u>) that refer to the enterprise architecture's elements. This interpretation also addresses the case in which a *stakeholder* is a team or a group, since <u>agents</u> are specialized by <u>Institutional</u> <u>Agents</u> and <u>Collective</u> <u>Agents</u>.

Nevertheless, we must carefully treat the fragment "or classes thereof" in the definition of stakeholder since it points us to the possibility of modeling classes of individuals, which we should interpret as some kind of <u>universal</u> in UFO that can be instantiated by <u>agents</u>. This represents a case of construct overload in the language, which could indicate the need to specialize the *stakeholder* concept into at least two different elements, one to represent an <u>agent</u> and the other to represent a <u>universal</u> that can be instantiated by <u>agents</u>. Further, since agents can be used to instantiate different sorts of <u>universals</u>, namely, <u>Agent Universals</u> (e.g. 'Person', 'Non-Governmental Organization'), <u>Social Roles</u> (e.g., 'Husband', 'Wife', 'Insurer', 'Insured') and <u>Social Role Mixins</u> (e.g., 'Customer'), the language would still collapse the different kinds of <u>universals</u>, again suggesting possible specializations of the stakeholder concept.

Now we focus on the concept of *Concern* and the relation *Stakeholder has Concern*. The description of the concept in the ME is abstract and states that a concern is "some key interest that is important to certain stakeholders in a system". The presence of the *stakeholder has concern* pattern in the model indicates that the stakeholder (an <u>Agent</u>) holds a particular <u>Belief</u>. In UFO, every <u>Belief</u> entails a <u>Proposition</u> which is the content of the <u>belief</u>, i.e., that which is held as true. The <u>proposition</u> in the case of a *stakeholder*'s *concern* refers to the importance that the *stakeholder* ascribes to certain *concern*. The *concern* itself, i.e., that which is important, is only represented in the ME as the label of the modeling concept. The properties or the characteristics which are supposed to be the focus of attention are not represented explicitly in the model. Thus, we refrain at this moment from a detailed interpretation of the possible contents of the <u>proposition</u> associated with a *stakeholder*'s *concern*. Nevertheless, we can state that, when a particular *concern* is associated with multiple *stakeholders*, the object

of the *concern*, its <u>proposition</u>, is shared, while the <u>belief</u> itself is particular of an individual.

The *assessment* concept "represents the outcome of the analysis of some concern". It indicates that some agent makes an analysis about a concern, drawing conclusions from this analysis. Semantically, in UFO, this means that some <u>agent</u> acquires new <u>beliefs</u> with <u>propositional contents</u> referring to a specific <u>situation</u>. The <u>propositional content</u> of the <u>belief</u> refers specifically to the properties or characteristics believed to be important (the object of the *concern*). This interpretation refers both to the *assessment* itself and the *assessment analyzes concern* relation, since an assessment, conceptually, needs to be about something. The ME does not indicate who performs the assessment. Thus, while the <u>propositional content</u> of the belief is settled (informally in the *assessment*'s label), the identity of the agent remains undetermined. Therefore, we interpret an *assessment* as a <u>proposition</u> of the <u>belief</u> of some undetermined <u>agent</u> (or agents). This shows that the ME might lack a construct to relate *assessments* and *stakeholders*, to determine the identity of the <u>agent</u> that holds the <u>belief</u>. This is particularly important as different *stakeholders* may come to different *assessments* of a shared *concern*. In our example, both the "Board" and the "Client" are concerned with "Customer Satisfaction"; consider the case in which the analysis of "Customer Satisfaction" by the "Board" lead to different conclusions when contrasted with the analysis of the concern by the "Client" (consider a situation in which the "Board" assesses that "Customer Satisfaction is High", while the "Client' assess that "Customer Satisfaction is Low"). This <u>situation</u> would be perceived differently by the two <u>agents</u>, which would hold <u>beliefs</u> with diverging <u>propositional contents</u>.

For the cases in which a stakeholder is interpreted as an <u>Agent Universal</u>, we understand that each instance of this universal has a <u>belief</u> with that propositional content, i.e., all stakeholder instances share the assessment.

B. Analysis of specializations of Intention

In this subsection we focus our attention to the concepts that specialize *Intention*, namely, *Goals*, *Principles* and *Requirements*.

A *goal* in the ME "represents some end that a stakeholder wants to achieve", which can be a "produced value or a realized effect". From the ME definition, we can observe that: (i) a *stakeholder* is committed to achieving a *goal*; and that, (ii) achieving the *goal* means bringing out certain effects in reality. Semantically, in UFO, this means that some <u>agent</u> has the <u>intention</u> of bringing about the <u>goal</u>. Thus, the <u>agent</u> intends to perform <u>actions</u> that have as <u>post-state</u> a <u>situation</u> (a state-of-affairs) that satisfies the <u>goal</u>. Since *goals* in the ME can be a "produced value or a realized effect", the <u>situations</u> that satisfies the <u>goal</u> are the ones in which this value has been produced or this effect is realized. Similarly to the case of *assessment*, the ME does not indicate the *stakeholder* who has the *goal*. Thus, while the <u>propositional content</u> of the intention is settled (informally in the *goal*'s label), the identity of the agent remains undetermined. Therefore, we interpret a *goal* as a <u>goal (proposition)</u> of some

undetermined agent (or agents). This shows that the ME might lack a construct to relate *goals* and *stakeholders,* to determine the identity of the agent that holds the intention of bringing about the goal.

In the ME, *goals* are defined in order to address *assessments*. The extension includes a *Goal addresses Assessment* relationship to capture this notion. Informally, the *goal* is motivated by the wish to change the situation that is revealed by the *assessment*. This wish can be understood as an implicit desire that is not satisfied in the situation revealed by the assessment. The agent then adopts a goal, committing to pursue the desired situation.

The *Principle* concept "represents a general desired property" that applies to any system in a given context. The idea is that the organization wants its systems (in the ME broad sense) to show specific properties. A principle would ideally impact in the design or in the actions of the systems. This concept is interpreted in UFO as a desire. A desire in UFO has a propositional content and also means that there is not necessarily an agent which has a commitment (self or social commitment) to act now on the desire to make it become true. The ME does not relate *principles* and *stakeholders*, thus we understand that the agent that is implied in a *principle* is the enterprise as a whole. If this is not the case, then the language should include additional relations to clarify the specific *stakeholders* that hold the *principle*. This may be relevant when conflicting principles are considered for different stakeholders in an intra- or inter-enterprise setting. The propositional content *P* of the desire that corresponds to the *principle* is the result of the application of the predicate *Q* on all systems in a given context, i.e., $P\equiv\forall s((System(s)\wedge ContextPrinciple(s))\rightarrow Q(s))$, where *System* holds for all systems, *ContextPrinciple* holds for all systems in the context of application of the principle and *Q* holds for the systems that exhibit the desired properties stated in the principle.

The *Requirement* concept is actually similar to the *principle* concept. A principle represents a general **desired** property that applies to any system in a context, while a requirement "represents a desired property that **must** be realized by a [specific] system". Similarly to *principle*, the definition of *requirement* seems to imply that a desire for specific properties exist, justifying an interpretation of requirement as a Desire in UFO. However, differently from principle, requirements must be satisfied if the system is to exist. This suggests an additional normative character of a requirement, which justifies an interpretation of a requirement as a normative description. The propositional content of the desire (representing the *requirement*) is formulated as a normative description which states that if a system is to exist, then it must satisfy the requirement's proposition. The propositional content *R* of the desire that corresponds to the *requirement* is the application of the predicate *Q* on a specific system (to-be) *A*, i.e., $R \equiv Q(A)$.. Ideally, the desire would lead to the adoption of intentions to satisfy the requirement, for example, by committing to actions to develop systems that satisfy the *requirement*. Nevertheless, this may not be the case for requirements with a low priority or requirements whose realization may not be worthwhile (in

which case the stakeholder will not commit to the actions that pursue requirements satisfaction).

Now we focus on the relations involving *Intention* and its specializations (*Principles, Requirements* and *Goals*). We start with the *realization* relationship that "models that some end is realized by some means." The realization relationship is applied in three different relations, and have different, but compliant interpretations for each, as follows:

(i) *Core element realizes Requirement.* The presence of this relationship indicates that the core element exhibits the required properties. In other words, the propositional content of the desire (stated as a normative description corresponding to the requirement *R*) is satisfied in all the situations which include the stated core element. Since, *R* is a predicate on the stated core element, *R* holds.

(ii) *Requirement realizes Goal.* The presence of this relationship indicates that the goal (proposition) *G* is satisfied in all situations that satisfy the propositional content *R* in the requirement. This relation reflects a logical relation between *R* and *G*, namely, $R \rightarrow G$.

(iii) *Principle realizes Goal*. The presence of this relationship indicates that the goal *G* is satisfied in all situations that satisfy the propositional content *P* of the principle. This relation also reflects a logical relation between *P* and *G*, namely, $P \rightarrow G$.

We should now refer to the *specialization* relation between *Principle* and *Requirement*. The current documentation of the ME states that "a principle needs to be specialized into requirements in order to enforce that some system conforms to the principle." We understand that the presence of this relationship indicates that the system that satisfies the requirement exhibit the properties stated in the principle. Let us remind that the propositional content *P* of the *principle* has the following structure: $P\equiv\forall s((System(s)\wedge ContextPrinciple(s))\rightarrow Q(s))$, where *Q* holds for the systems that exhibit the desired properties stated in the principle. Thus, formally, the presence of the *specializes* relationship indicates that the predicate *Q* (properties stated in the principle) is satisfied in all situations that satisfy the propositional content *R* in the requirement. Since *R* is a proposition that states properties of a particular system (let us call this system *S*), then this relation reflects a logical relation between *R* and *Q(S)*, namely, $R \rightarrow Q(S)$.). In other words, the satisfaction of the requirement (in *S*) satisfies the principle's properties when applied to *S*.

The *conflict* relationship "is used to describe that two intentions cannot be realized both, and as such are in conflict with each other". In other words, one intention leads the world to a state in which the other intention cannot be satisfied. In UFO, we can say that from the current situation there are no events (or complex sequences thereof) that would lead to a situation in which the propositional content of both *intentions* (*Principle/Goal/Requirement*) would hold. (Note that this is different from the case in which the propositional contents of the *intentions* are mutually incompatible, i.e., cannot hold simultaneously. According to our interpretation, *intentions* with incompatible propositions are in *conflict* with each other. Nevertheless, there are *intentions*, which, while in principle are compatible with

each other, cannot be accomplished from the current situation. For example, an organization holds U$100.000,00 for investments and intends to acquire two machines that are worth U$100.000,00 each. While the propositional contents are not mutually incompatible there are no events (or complex sequences thereof) that would lead to the accomplishment of both *intentions*.

The *contribution* relationship models that "the realization of some intention contributes positively or negatively to the realization of another intention". In a *positive contribution*, less effort is required to reach a situation that satisfies the propositional content of B from the situation that satisfies the propositional content of A. In a *negative contribution*, more effort is required to reach a situation that satisfies the propositional content of B from the situation that satisfies the propositional content of A.

C. Common relationships analysis

In this section we analyze the relationships that are common for all the concepts described in ArchiMate and have no specific definition in the ME, namely aggregation and specialization.

According to the ME whitepaper, "the aggregation relationship models the decomposition of some intention, i.e., a goal, requirement or principle, into more fine-grained intentions." While this definition only discusses explicitly the metaclasses which specialize of *intention*, according to ArchiMate, "the aggregation relationship can relate any instance of a concept with another instance of the same concept". Thus, we conclude that the relationship can also be used to decompose *assessments*, *concerns* and *stakeholders*.

At first observation, the relation seems to represent a shareable part-whole relation that makes no commitment on whether it is complete, or whether any or all parts are mandatory or optional. However, considering that the interpretations of *Concern, Assessment, Goal, Requirements* and *Principles* all rely on propositions (*Concern, Assessment and Goal* are propositions and *Requirements* and *Principles* are desires which have as content propositions), we can define this relationship more accurately as a logic relation between propositions. More specifically, the propositional content P_i of each of the *n* fine-grained model elements appears as a term in the propositional content P of the composed model element, formally, $(P \leftrightarrow P_1 \bullet_1 P_2 \bullet_2 \dots \bullet_{n-1} P_n \bullet_n Z))$, where $\bullet_i$ represents either the disjunction or the conjunction operator and an optional term Z represents any other proposition that may be used to derive P and is not explicitly modeled in the aggregation. Z captures the ambiguity regarding the notion of incompleteness that is associated with the aggregation concept. The ability to model an incomplete aggregation is particularly useful, since one may not be able to list all possible decompositions of an intention, many of which may be unknown at the time of modeling. Furthermore, a modeler may choose to omit the least relevant decompositions when faced with an aggregation with numerous decompositions. Nevertheless, the language could also have opted to distinguish between an incomplete and a complete aggregation. In a complete aggregation $(P \leftrightarrow P_1 \bullet_1 P_2 \bullet_2 \dots \bullet_{n-1} P_n)$ for which the

satisfaction of all P_i entails the satisfaction of P. The fact that the operators $\bullet_i$ are undefined is a characteristic of the language. This is different from certain goal modelling approaches (such as Tropos) where there is a distinction between the AND- and the OR-decomposition of goals. From the sole perspective of expressiveness and clear semantics, the ME could be specialized with additional elements to capture the distinction between AND- and OR-decomposition.

The interpretation of the aggregation relationship for the *stakeholder* concept depends on the interpretation of the *stakeholder* concept, which, as we have discussed can represented either as an agent individual or as an agent universal. In the case in which it represents an agent individual, the aggregation represents either: (i) a part-whole relationship between an institutional agent (the whole) and the aggregated agents (the parts) called componentOf, or (ii) a part-whole relationship between a collective agent (the whole) and the aggregated agents (the parts) called memberOf [13]. The distinction, however, cannot be expressed in the *stakeholder* concept (being captured informally in the labels and description of a stakeholder). In the case in which the *stakeholder* concept represents an agent universal, we interpret the aggregation relationship as a shareable part-whole relation that makes no commitment on whether it is complete, or whether any or all parts are mandatory or optional. When instantiated this relationship will either represent the componentOf relation or the memberOf relation depending on the natures of the related elements.

We proceed to analyze the *specialization* relationship when applied to *Concern, Assessment, Goal, Requirements* and *Principles*. Considering that the interpretations of *Concern, Assessment* and *Goal* are propositions and *Requirements* and *Principles* are desires which have as content propositions, we can define this relationship as a logic relation between propositions. More specifically, the set of situations that satisfy the propositional content P of the specialized model element is a subset of the set of situations that satisfy the propositional content P' model element being specialized. Thus, formally, $P \rightarrow P'$.

When considering the *specialization relationship* applied to the *stakeholder* concept, we believe that this relationship can only be applied meaningfully in the case in which a *stakeholder* is used to represent an agent universal. In that case, all instances of the specialized agent universal are instances of the agent universal being specialized.

D. Example in terms of UFO

In this subsection we apply the proposed interpretation to the example in Figure 2.

The example shows the 'Board' *stakeholder*, which we interpret here as representing an Institutional Agent (the organization's board) and the 'Customer' *stakeholder*, which we interpret here as representing either an Agent Universal or Social Role which will be instantiated by Agents that are customers of the organization.

The model shows that the Institutional agent 'Board' has a belief whose content refers to the importance of 'Costs' and

a belief whose content refers to the importance of 'Customer Satisfaction'. The model shows that every agent instantiating 'Customer' holds a belief with the same propositional content (on the importance of 'Customer Satisfaction').

The model also shows that some assessment has been conducted considering the 'Customer Satisfaction' *concern*, leading to the conclusion that there are 'Complaining Customers'. In other words, some (undetermined) agent holds a belief whose propositional content refers specifically to properties or characteristics believed to be important ('Customer Satisfaction'). In this case, it is unclear as to whether the content of the *assessment* is shared by the identified *stakeholders*, so we cannot know whether the belief is held by each agent instantiating 'Customer', by the 'Board' or by all stakeholders. We reaffirm that the ME is not expressive enough to satisfactorily represent the cases in which different and possibly contradictory *assessments* are made by different *stakeholders*. These cases may be frequent which would justify adding language constructs to relate *stakeholders* and *assessments*. Additionally, in light of the proposed interpretation, careful analysis of the labels of the assessment modeling element reveals a rather indirect choice of text in the example ('Complaining Customers'), with no explicit mention of the concern ('Customer Satisfaction'). The interpretation we have provided suggests that a more explicit reference to the concern would be desirable (e.g., renaming the assessment to 'Customer Satisfaction is low').

The *goal* 'Reduce workload employees' can be interpreted as representing that some (undetermined) agent holds the goal of reducing the workload of employees and commits on acting to pursue a situation that satisfies the propositional content of his/her intention. The goal 'Reduce workload employees' aggregates the *goals* 'Reduce manual work' and 'Reduce interaction with customer'. According to our interpretation, the model suggests the existence of a logical relation between the content of 'Reduce workload employees' and the contents of 'Reduce manual work' and 'Reduce interaction with customer'. As discussed earlier, the model does not precisely identify this relation, thus it is possible that the modelers mean that both subgoals need to be attained for the aggregated goal to be satisfied, or that one of the subgoals needs to be attained for the goal to be satisfied.

The model further states that *principle* 'Systems should be Customer Facing' *realizes* the *goals* 'Reduce manual work' and 'Reduce interaction with customer'. This means that whenever the desired proposition 'Systems should be Customer Facing' is satisfied the goals are satisfied. (And, thus, 'Reduce workload employees' is satisfied.)

The relationship of specialization between the *principle* 'Systems should be customer facing' and the *requirements* 'Provide on-line information service' and 'Provide on-line portfolio service' states that whenever a *system* meets the *requirements* proposition, this *system* complies to the *principle* proposition, i.e., the *principle* proposition holds when applied to that specific *system*. This model shows that if a *system* provides on-line information service or provides on-line portfolio service it is a customer facing *system*. In the scope of the model, if the enterprise's systems satisfy the requirements, then the overarching goal 'Reduce workload employees' is satisfied.

V. RELATED WORK

An early approach to have suggested the use of foundational ontologies in determining the semantics of modeling languages was discussed by Evermann and Wand in [18]. The authors propose a mapping of UML constructs to the BWW ontology and show that by mapping UML constructs to well-defined ontological concepts, clearer semantics can be obtained. In [13], the UML class diagrams have been subject to thorough review using UFO as a semantic foundation. The author has created the so-called OntoUML as a result of this review; an ontologically well-founded conceptual modeling language.

A number of enterprise modeling approaches have been subject to ontology-based analysis in recent years. For example, in [19], the authors did an ontological analysis to uncover ontological deficiencies regarding modeling languages and its use in an organization. The authors' found nine ontological deficiencies related to modeling when using the Business Process Modeling Notation (BPMN). In [9] and [20], the authors performed an ontological analysis and interpretation of the ARIS framework. The authors' intention was to define the semantics of ARIS concepts and relationships in terms of UFO. Some problems regarding the ARIS Method were exposed and possible solutions to these problems were proposed. In [10], the authors have used UFO as a semantic foundation to analyze several enterprise modeling approaches with respect to the representation of role-related concepts (what is called "active structure" in the ArchiMate framework, or that which fills the "who" column of Zachman's framework). Several cases of semantic overload and lack of expressiveness have been detected.

Concerning specifically the goal domain, [21] analyzes the Tropos language and proposes an interpretation of the language concepts in terms of UFO. [4] discuss the semantic interpretation of a subset of Tropos and the goal modelling constructs in the ARIS framework. The authors semantically integrate Tropos and ARIS defining the semantics of both languages in terms of the UFO and providing a correspondence between them.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we have presented an ontology-based semantics for the proposed ArchiMate Motivation Extension (ME). The extension includes concepts such as concerns, assessments, goals, principles and requirements to ArchiMate and is particularly expressive in the goal-domain when contrasted with a number of enterprise modeling approaches [6].

We have argued that careful definition of the semantics of motivation domain concepts is required, especially since this domain addresses subjective aspects of the enterprise, which have eluded clear semantics definition in the past (see [6] which discusses the modeling constructs of a number of enterprise modeling approaches).

The ontological analysis we have performed allowed us to reveal some issues with the ME. With respect to lack of expressiveness the ontological analysis allowed us to identify

the absence of constructs in the language to relate the *stakeholder* concept to the concepts of *assessment, principle, requirement* and *goal*. As a result, the ME is currently unable to capture the cases in which different assessments are performed by different stakeholders with shared concerns. Analogous problems occur when dealing with principles, requirements and goals. We believe that many of the benefits of goal modeling stem from the possibility of contrasting the goals of the various enterprise stakeholders, which would require at least the identification of the relation between stakeholders and their goals. The importance of the identification of the stakeholders may be even more evident in an inter-organizational model, since different organizations will likely have different goals, as well as will likely apply different principles and requirements on their systems.

The ontological analysis also showed us that the language has a construct overload problem and lacks the expressiveness to distinguish between a stakeholder representing a specific agent and a stakeholder representing any agent instantiating a particular agent universal.

We have also identified some problems resulting from the usage of the generic relations of ArchiMate in the ME, more specifically, the consequences of the unqualified usage of the specialization relation between stakeholders. Since the stakeholder construct is used to represent entities of different ontological natures (agent individuals and agent universals), this relation does not always have a meaningful interpretation. This problem in the ME becomes evident when a stakeholder representing an agent universal (e.g., Professor) specializes a stakeholder representing an agent individual (e.g., John); or when a stakeholder representing an agent individual (e.g., Mary) specializes another stakeholder also representing an agent individual (e.g., John).

Another issue raised by the ontological analysis is the lack of sophistication in goal refinement relations. The extension is currently unable to distinguish between AND- and OR- goal decompositions. This distinction is instrumental to goal analysis and is one of the basic distinctions discussed in the goal modeling literature (see, e.g., [2]).

As future work, we intend to carry out a thorough ontological analysis of ArchiMate's core concepts, and consider the implications of the semantics of the core ArchiMate concepts to the ME. We also intend to analyze and interpret BPMN with the objective of defining how to use it in tandem with ArchiMate and the ME to model detailed business process views while relating those to the overall enterprise goals. We will also pursue an ontological interpretation for the TOGAF content metamodel [17], aiming at systematically addressing the alignment of ArchiMate and TOGAF. Our central idea is to have coherent descriptions of the enterprise towards its semantic integration.

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TABLE I.   SUMMARY OF THE ME ONTOLOGICAL INTERPRETATION

ME Concept	Context Information	Ontological Interpretation
Stakeholder	"Stakeholder can be an individual, team, organization or classes thereof."	Agent or universal that can be instantiated by agents.
Concern and Stakeholder has Concern relation	A *concern* is "some key interest that is important to certain stakeholders in a system". *Concerns* can be shared.	The propositional content of an agent's belief. The proposition in the case of a *stakeholder*'s *concern* refers to the importance that the *stakeholder* ascribes to certain *concern*.
Assessment and Assessment analyzes Concern relation	An *assessment* "represents the outcome of the analysis of some concern".	A belief of an undetermined agent. The propositional content of the belief refers specifically to the properties or characteristics believed to be important (the object of the *concern*) - in a specific situation
Goal	"A goal is some end that a *stakeholder* wants to achieve"	A goal of an undetermined agent. A goal is the propositional content of an agent's intention.
Goal addresses Assessment	"new or adapted business goals" can be defined to address Assessments	Some agent adopts a goal committing to pursue a desired situation. The *goal* is motivated by the wish to change the situation that is revealed by the *assessment*. This wish can be understood as an implicit desire that is not satisfied in the situation revealed by the assessment.
Requirement	"Represents a desired property that must be realized by some specific system." However, *requirements* must be satisfied if the system is to exist.	A desire whose propositional content is formulated as a normative description, stating that if a system is to exist, then it must satisfy the *requirement's* proposition.
Principle	"Represents a general desired property that applies to any system in a given context."	Desire. The propositional content P of the desire is the result of the application of the predicate Q on all systems in a given context, i.e., $P \equiv \forall s$ $((System(s) \wedge ContextPrinciple(s)) \rightarrow Q(s))$, where *System* holds for all systems, *ContextPrinciple* holds for all systems in the context of application of the principle and Q holds for the systems that exhibit the desired properties stated in the principle.
Contributes to relation	The realization of some intention A contributes positively or negatively to the realization of another intention B.	Less/more effort is required to reach a situation that satisfies the propositional content of B from the situation that satisfies the propositional content of A.
Conflicts to relation	Used to describe that two intentions cannot be realized both, and as such are in conflict with each other.	There are no events (or complex sequences thereof) that would lead to a situation in which the propositional content of both *intentions* (*Principle/Goal/Requirement*) would hold.
Core element realizes Requirement	The presence of this relationship indicates that the *stakeholder* believes that the core element exhibits the *required* properties.	The propositional content of the desire (corresponding to the *requirement R*) is satisfied in all the situations which include the stated *core element*.
Requirement realizes Goal	Whenever the *requirement* is satisfied the *Goal* is also satisfied.	The goal (proposition) G is satisfied in all situations that satisfy the propositional content R in the requirement.
Principle realizes Goal	Whenever the *principle* is satisfied the *Goal* is also satisfied.	The goal G is satisfied in all situations that satisfy the propositional content P of the principle
Aggregation Relationship (between elements of the same type)	In case of *Concern, Assessment, Goal, Principle and Requirements* since they rely on propositions the aggregation relation is interpreted as a relation between propositions.	The propositional content P_i of each of the n fine-grained model elements appears as a term in the propositional content P of the composed model element, formally, $(P \leftrightarrow P_1 \bullet_1 P_2 \bullet_2 \dots \bullet_{n-1} P_n \bullet_n Z))$, where $\bullet_i$ represents either the disjunction or the conjunction operator and an optional term Z represents any other proposition that may be used to derive P and is not explicitly modeled in the aggregation.
Aggregation Relationship (between *stakeholders*)	When *stakeholder* represents an agent	(i) A part-whole relationship between an institutional agent (the whole) and the aggregated agents (the parts) called componentOf, or (ii) a part-whole relationship between a collective agent (the whole) and the aggregated agents (the parts) called memberOf [13]
	When *stakeholder* represents an agent universal	When instantiated this relationship will either represent the componentOf relation or the memberOf relation depending on the natures of the related elements.
Specialization Relationship (between *intentions* of the same type)	Considering that the interpretations of *Concern, Assessment, Goal, Requirements* and *Principles* rely on propositions, we can define this relationship as a logic relation between propositions.	The set of situations that satisfy the propositional content P of the specialized model element is a subset of the set of situations that satisfy the propositional content P' model element being specialized. Thus, formally, $P \rightarrow P'$.
Specialization Relationship (between *stakeholders*)	We believe that the *specialization* relationship can only be applied meaningfully to the *stakeholder* concept, whenever a *stakeholder* is used to represent an agent universal being specialized.	All instances of the specializing agent universal are instances of the specialized agent universal.
Requirement specializes principle	"indicates that an object is a specialization of another object. In the current context, this relationship is used in particular to describe that a principle is specialized into a requirement".	A predicate Q (which contains the properties stated in the principle) is satisfied (when applied to that specific system) in all situations that satisfy the propositional content R in the requirement.